Atmospheric Ozone and UV-B Radiation

Natural Variability and Enhanced Climate Prediction

Long-Term Climate Change including Global Warming

Ecosystem Change and Biodiversity

Human Dimensions and Economics

EARTH OBSERVING SYSTEM:

SCIENCE CONTRIBUTIONS TO NATIONAL GOALS AND INTERESTS

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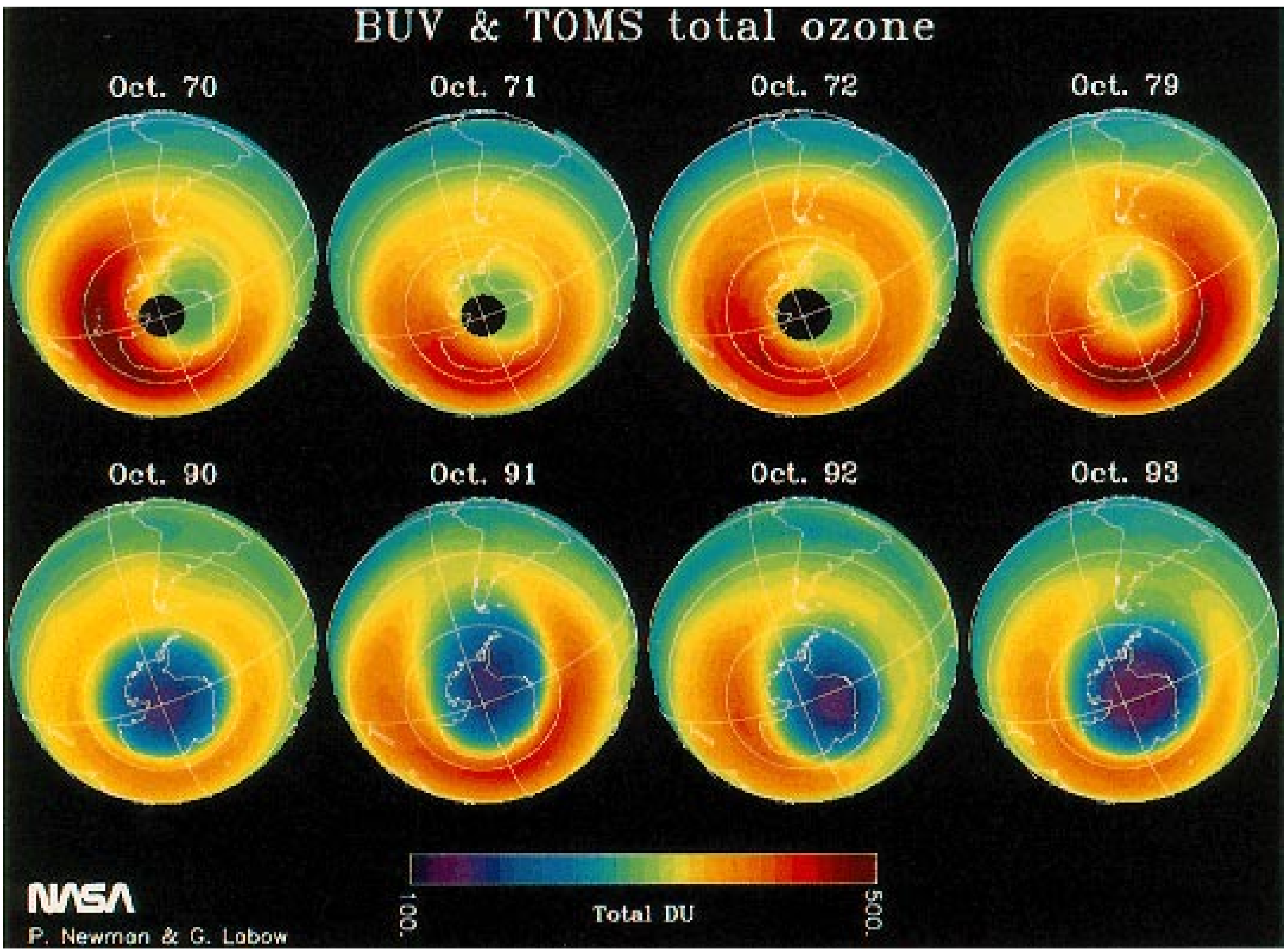
INTRODUCTION

Much of the research underway and planned as part of NASA's Earth Observing System (EOS) is directed toward the highest priority elements of the US Global Change Research Program (USGCRP). In order to elucidate the importance of EOS contributions for national interests and needs, the Science Executive Committee of the Investigator Working Group (IWG) instituted a survey based on the preliminary set of questions and products developed by the USGCRP office and other agencies. The survey was divided into the five major themes, the national needs for each theme, and the products required to answer the most pressing scientific questions directed toward these national needs. These themes are:

The discussion which follows is a synthesis of the responses of EOS investigators and an overview by the authors. These responses indicate the importance of EOS. EOS directly addresses national requirements for scientific understanding of atmospheric ozone, natural variability and enhanced climate prediction, and long-term climate change. EOS provides fundamental measures related to ecosystem change and aids in biodiversity research. Much of EOS research is a prerequisite for significant elements of the human dimensions research plan.

A glossary is provided at the end of this document to explain the EOS instrument names used throughout this text.



The history of the Antarctic ozone hole from 1970 to 1994.

1 ATMOSPHERIC OZONE AND UV-B RADIATION

The National Interest

Ozone is a primary shield from harmful ultraviolet radiation (UV-B) and is a significant contributor to the global radiative energy balance through solar absorption and IR radiation.

Scientific Background

The development of the Antarctic ozone hole and the global depletion of stratospheric ozone is well documented from satellite (Nimbus 7 SBUV, TOMS, Meteor TOMS, SAGE II, and NOAA SBUV2), ground based (Dobson network), and in situ (aircraft and balloon) measurements. The depletion of stratospheric ozone has been tied to two major causes. First, ozone depletion is clearly associated with a sixfold increase in stratospheric chlorine above natural levels, in large part due to the human emission of chloroflurocarbons. The increasing levels of stratospheric chlorine have been implicated in the development of late winter and spring polar ozone depletions. Second, significant volcanic injection of sulfur dioxide into the stratosphere can lead to a temporary (several years) ozone depletion apparently associated with the increase of sulfate aerosols in the stratosphere. Although the chemistry of volcanic depletions is not completely understood, the effect can be significant. The eruption of Mt. Pinatubo has been correlated with a 35% reduction in stratospheric ozone at northern hemisphere latitudes. Prior to the eruption of Mt. Pinatubo, the satellite and ground based data showed an additional midlatitude ozone decrease of slightly less than 1% per year. Although some modelers attribute this nonpolar trend to industrial chlorine loading of the stratosphere, the exact cause is still under research. Ozone depletion can also be the result of stratospheric emissions for the increasing fleet of subsonic aircraft.

Ozone is also a greenhouse gas with strong infrared bands. In the tropics, ozone in the cold lower stratosphere intercepts surface IR radiation, heating the stratosphere. At polar latitudes, ozone cools the stratosphere. Ozone loss will affect the energy balance of the lower stratosphere and upper troposphere.

Heterogeneous chemistry on aerosols plays a significant role in ozone loss. We also know that aerosol formation is temperature dependent. Thus global cooling of the stratosphere due to increasing carbon dioxide may increase ozone loss which in turn would amplify the stratospheric cooling in some regions and increase surface greenhouse warming in others.

Science Requirements to Address National Needs

- The detection, causes and impacts of significant changes in stratospheric ozone.

EOS CONTRIBUTIONS

The Earth Observing System addresses critical questions in the national interest including the detection and prediction of ozone depletion, the isolation of human versus natural factors forcing changes in atmospheric ozone, the response of atmospheric ozone to human forcing, and an understanding of the uncertainties associated with ozone depletion. For atmospheric ozone the key questions and EOS contributions are:

1. What are the long term and short term changes in stratospheric ozone?

Ozone Profiles. HIRDLS and MLS will make daily global ozone profile measurements. SAGE III will make high precision solar occultation ozone profiles as part of the long term trend series begun by the predecessor SAGE I and II instruments. The CHEM international instrument will provide daily column ozone amount. AIRS will measure the vertical distribution of ozone in the troposphere and five layers in the stratosphere using infrared. MODIS will measure total column ozone twice daily with better than 20% accuracy. Both of these measurements can provide a backup for the more accurate HIRDLS, MLS, SAGE III and CHEM observations.

Calibrated Historical Data Sets. EOS investigators will produce long term calibrated ozone data sets based on earlier Nimbus 7 (SBUV, TOMS), Meteor TOMS, EP TOMS, SAGE I, SAGE II, UARS (MLS, HALOE, ISAMS, CLAES) and NOAA SBUV/2 measurements. The ozone mapping instruments on ERS-2 and ENVISAT will provide additional ozone data sets.

2. What are the human and natural forcing agents controlling stratospheric ozone? What has been and will be the response of stratospheric ozone and UV-B radiation to human forcing?

Catalysts. HIRDLS, MLS and SAGE III will measure polar stratospheric clouds and aerosols. These measurements will provide an understanding of the role of heterogeneous and nitrogen radicals which catalyze ozone destructions, the chlorine reservoir species and source gases including industrial chemicals (CFC's), nitrogen compounds and aerosols emitted directly by high-flying aircraft, and volcanoes.

Stratospheric Clouds and Aerosols. SAGE III and HIRDLS will measure polar stratospheric clouds and aerosols. These measurements will provide an understanding of the role of heterogeneous chemical changes in producing ozone variability. MLS will contribute measurements which are not degraded by clouds or volcanic aerosols, allowing critical observations in the presence of polar stratospheric clouds and thick aerosol layers which form following volcanic eruptions.

Stratospheric Temperature Profiles. MLS, HIRDLS and AIRS will provide accurate global daily stratospheric temperate profiles. These measurements, combined with 4-D data assimilation, are used to determine the stratospheric circulation and transport. Year to year variation in the stratospheric circulation is a major factor controlling stratospheric ozone.

Solar UV Radiation. SOLSTICE will make highly accurate solar UV radiation measurements. Solar variation in UV flux throughout the solar cycle are a major factor controlling the global ozone amount.

UV-B Transmissions. EOS monitoring of clouds and the radiant energy budget will provide a diagnostic measure of the UV-B transmission which is cloud dependent. CERES, AIRS, MODIS and MISR will produce cloud forcing products and cloud radiative properties useful for UV-B analysis.

Human-Induced versus Natural Depletion. EOS investigators will use the EOS measurements of stratospheric ozone, minor constituents, temperatures, UV flux, and aerosols to separate natural ozone variations from human-induced ozone depletion over the EOS period. These measurements can be linked to previous measurements made by the Nimbus 7 and UARS instrument compliments, the SAGE, TOMS and SBUV/2 satellite instrument series, aircraft and ground based measurement to determine trends in trace gases.

Chemical Transport Models. EOS investigators will develop 3- dimensional chemical transport models of the stratosphere, in predictive and diagnostic modes, which can be utilized to calculate radical trace gas concentrations, estimate ozone losses, and calculate the UV-B flux. EOS measurements will be used to validate those models.

3. What will be the climate impact of changing radiatively active stratospheric trace gases (ozone, water, CFC's, N_2O, etc.)?

Detection of Ozone Radiative Forcing Changes. HIRDLS, MLS, and SAGE III make essential contributions to detecting ozone depletion and water vapor trends in the troposphere and lower stratosphere where radiative forcing changes are critical for climate. SAGE III high precision ozone and water measurements are especially important in determining changes since the 1980's since these measurements can be linked to SAGE III predecessor instruments.

Aerosol Radiative Forcing Changes. SAGE III and HIRDLS measurement of aerosols in the upper troposphere and lower stratosphere are essential in determining the aerosol radiative forcing. Determination of this forcing is especially important in post volcanic eruption periods when formation of thick stratospheric sulfate aerosols layers produce global cooling.

". . . global cooling of the stratosphere due to increasing carbon dioxide may increase ozone loss which in turn would amplify the stratospheric cooling in some regions and increase surface greenhouse warming in others."

Water Vapor Radiative Forcing Changes. MLS makes daily, global measurements of upper tropospheric water vapor and temperature through the cloud fields. MLS measurements can be used to assess the radiative forcing of water vapor and can be linked to cloud formation and moisture transport processes when combined with MODIS, CERES and AIRS measurements.

CFC's and N_2O Radiative Forcing Changes. HIRDLS and MLS make measurements of CFC's and N_2O in the lower stratosphere.

Assimilated Data Sets. EOS investigators will assimilate the aerosol, temperature, and water vapor measurements of SAGE III, HIRDLS and MLS to produce global meteorological data sets which will be used for climate studies.

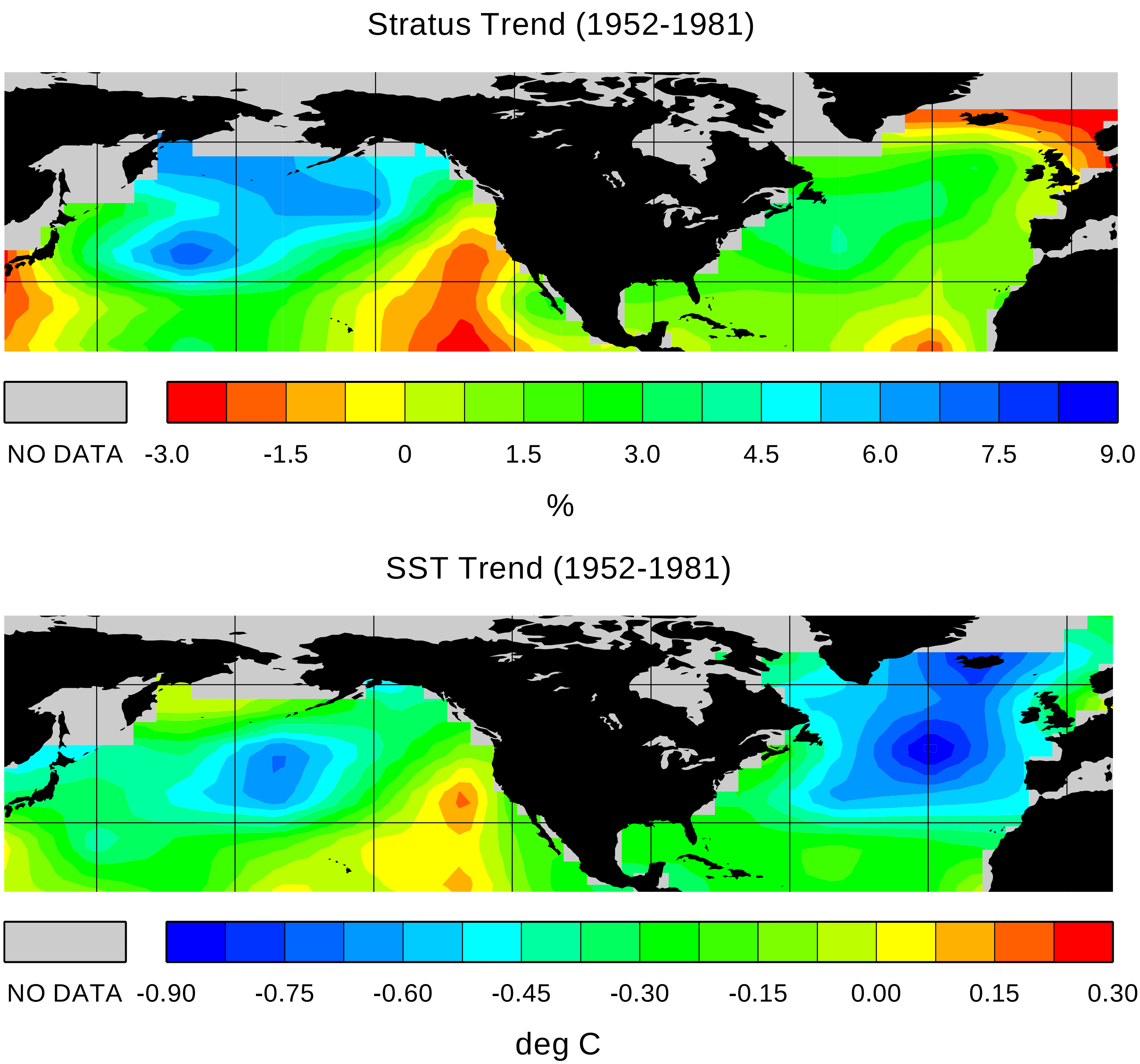
4. What are the uncertainties and what is the potential for change?

Early Detection. SAGE III, MLS and HIRDLS ozone measurements will provide the earliest-possible detection of ozone depletion. Despite the regulation of CFC production, additional ozone decreases will occur in response to the unprecedented high chlorine abundances expected during the next decade.

Major Uncertainties in Stratospheric Chemistry. EOS chemical measurements (MLS, HIRDLS, SAGE III and SOLSTICE) address major uncertainties in understanding stratospheric chemistry by measuring the minimum minor constituent set required to understand the processes that control ozone. The measured constituents include a radical from each of the major catalytic ozone loss families, the major reservoir gases, the major source gases for those radicals, temperature, aerosols, and UV flux. This set of measurements will be the most complete global measurements since UARS, and is the minimum set required to connect changing ozone amounts to chemical processes within the stratosphere.

Links to Stratospheric Cooling. EOS measurements, including stratospheric temperatures (AIRS, HIRDLS, MLS) will increase our understanding of the potential ozone decrease in response to the stratospheric cooling caused by increasing atmospheric CO_2.

Aerosols. EOS SAGE III and HIRDLS will monitor the formation of sulfate aerosol layers following volcanic eruptions and the impact of these layers on the natural variability in ozone chemistry and enhancement of the human forcing on ozone depletion. They will provide daily measurements of the location and extent of polar stratospheric clouds which are primary sites for heterogenous chemical reactions which give rise to ozone loss.



Related changes in low stratus cloud cover (top) and sea surface temperature (bottom) have occurred between 1952 and 1981 over the North Atlantic and North Pacific Oceans. Over most of this region, sea surface temperature has fallen while cloudiness has increased. These long-term trends are believed to arise from the complex natural dynamics of the coupled atmosphere-ocean system rather than from anthropogenic influences. Identification of a global warming signal will require it to be clearly distinguishable from such natural variability. (Norris and Leovy, 1995)

2 NATURAL VARIABILITY AND ENHANCED CLIMATE PREDICTION

The National Interest

The skillful prediction of precipitation and temperature anomalies months to years in the future can yield improved production and distribution of agricultural and forestry products, improved planning for energy generation and utilization, and more effective responses to floods and droughts. The goal is therefore to use short term (seasonal and interannual) climate forecasting for social and economic benefit.

Scientific Background

Predictability on seasonal and interannual time scales has already been demonstrated for some aspects of the climate system, particularly for interannual sea surface temperature changes in the tropical Pacific Ocean and their relation to weather. In addition to its immediate practical benefits, improved short term climate forecasting, because it requires a comprehensive knowledge of the atmospheric circulation and its interaction with the ocean and the land surface, contributes substantially to the predictions of long-term greenhouse warming. Verification of short term climate forecasts and resulting improvements in forecasting models contribute directly to the improvement of global greenhouse warming forecasts on decadal and longer time scales, especially the regional variations in climate change. In addition, detection of long term human-induced climate change requires an understanding of the natural variability inherent in the climate system which produces most of the variability on seasonal and interannual time scales.

Science Requirements to Address National Needs

- Operational predictions of interannual climate fluctuations up to one year in the future.
- Detection of natural climate variations on decadal time scales and identification of their causes and impacts.

EOS CONTRIBUTIONS

EOS will help define the natural and human factors that influence seasonal to interannual climate. A significant fraction of natural climate variability is governed by interaction of the atmosphere with global sea surface temperature, land moisture, vegetation, snow and sea ice. Additional variability is introduced from solar variability and volcanic eruptions. Human-induced modifications of atmospheric chemistry may alter the nature of seasonal to interannual variability. The EOS contributions to understanding climate variability will enhance the ability to predict climatic variations and change from seasons to decades in advance. The key questions and EOS contributions include:

"Human-induced modifications of atmospheric chemistry may alter the nature of seasonal to interannual variability. The EOS contributions to understanding climate variability will enhance the ability to predict climatic variations and change from seasons to decades in advance."

1. What are the natural and human factors that affect the seasonal to interannual climate and its anomalies?

Ocean-Atmosphere Interaction. EOS will contribute substantially to the understanding of ocean-atmosphere interactions. Investigators will be able to combine altimetry (TOPEX / Poseiden, ERS-1, ERS-2, TOPEX follow on, and EOS ALT), scatterometry (NSCAT, AMI, Seawinds), ocean color (MODIS, Seawifs, EOS-COLOR), and sea surface temperature measurements (MODIS, AIRS / AMSU / MHS), assimilate these observations into forecasting models and resolve major characteristics of the surface oceans responsible for natural variability. These observations combined with the temperature and humidity measurements of AIRS / AMSU and the cloud-radiation budgets from CERES, will allow investigators to connect sea surface temperature variations with the large-scale and mesoscale circulations and their associated cloud cover, and improve boundary layer models which describe air-sea interaction. Global assimilation of these data will provide operational products necessary for predictions of interannual fluctuations and will also contribute to our understanding of the coupled ocean-atmosphere interactions and the prediction of phenomena such as El Niño. EOS (CERES, MODIS, AIRS and MISR) will provide a strong basis for monitoring variability in cloud properties (amount, type, liquid water content) which may play an important role in natural interannual variability of the climate system. SAGE III, HIRDLS and MLS contribute observations to assess the interannual variability of radiatively active trace gases (ozone, CH_4, F_{11}, F_{12}, nitrous oxides) and water vapor in the upper troposphere and lower stratosphere which may participate in climate variability.

Land-Atmosphere Interaction. EOS measurements of snow cover, soil moisture, surface temperature, land cover, vegetation characteristics, surface albedo, atmospheric temperature and humidity (ASTER, MODIS, MISR, CERES, AIRS / AMSU / MHS, MIMR) will be essential to initialize, and validate the land component of climate model forecasts and to assess the role of the land surface in governing seasonal to interannual variability at regional to global scales. EOS measurements will provide substantial improvements in comparison with existing capabilities (e.g. AVHRR). The ability of EOS to monitor land-surface energy and moisture fluxes (particularly soil moisture) using a new generation of spatially distributed hydrologic models (based on MODIS, ASTER, AIRS, MIMR and other satellite data) will help to better understand land-atmosphere climate interactions. EOS regional assessments which monitor hydrologic parameters (precipitation, evaporation, water vapor, stream flows, glaciers and snow cover) sensitive to climate change and which incorporate historical observations provide baselines for determining changes in variability.

Aerosols. EOS will be able to characterize the abundance and properties of natural and human-made tropospheric aerosols which may change the effect of greenhouse gases on climate. MODIS, MISR and EOSP will detect regional and global changes of aerosol distribution and variability of their size. They will be able to track several sources of aerosol (e.g. MODIS observations of fires as a source of biomass burning aerosol). EOSP will also determine the aerosol refractive index, a measure of the aerosol composition. Wind blown dust from arid regions will be monitored for major source regions. SAGE III will increase our understanding of aerosol loading and removal.

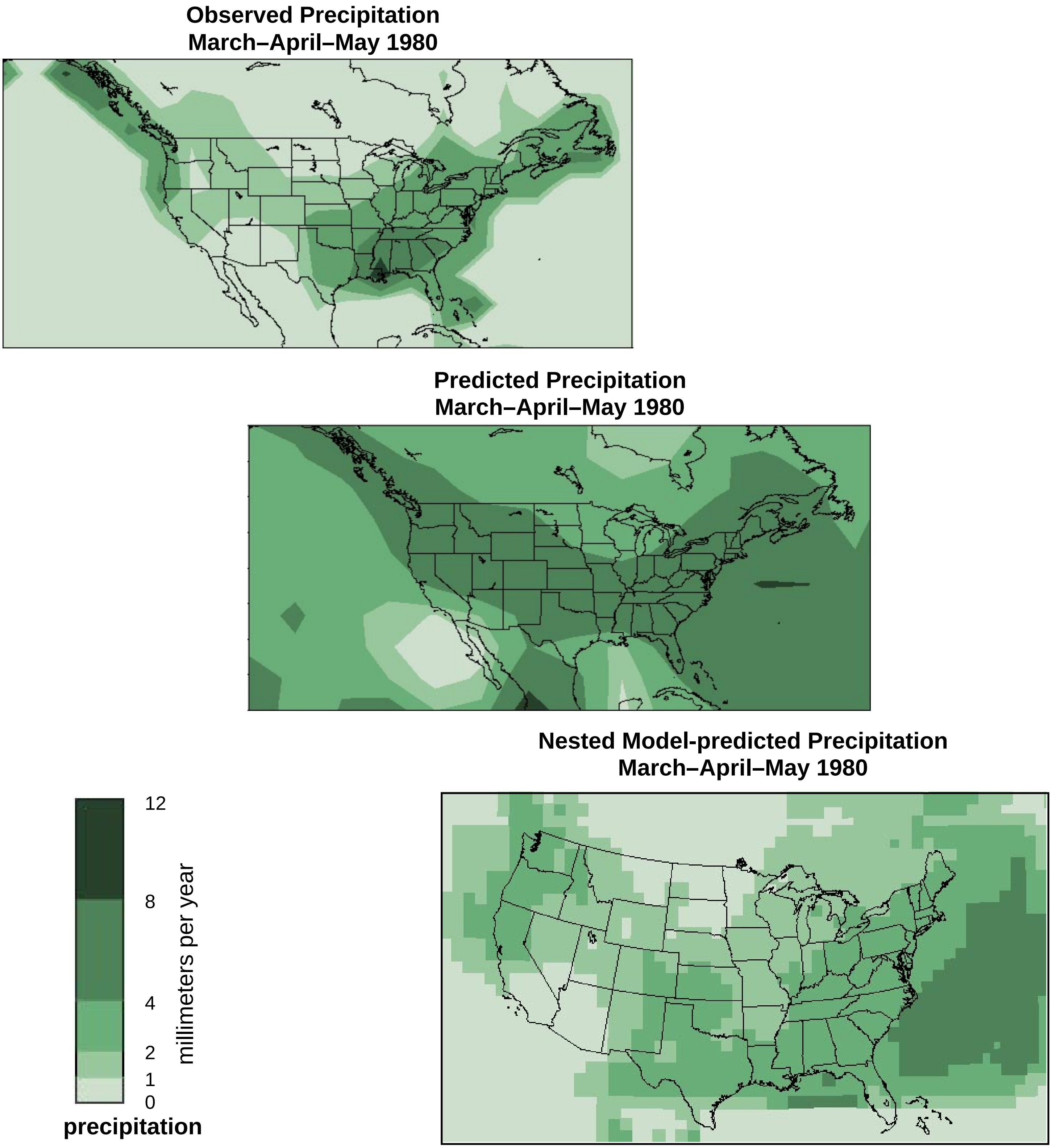
EOS will be able to track and characterize volcanic eruptions which produce climatic variability on time scales of seasons to years. MISR and ASTER can track the height of plumes, MODIS and MISR the dispersal of the particulates, TOMS, TES, and MLS the dispersal of SO_2, and MISR, HIRDLS and SAGE III the dispersal of stratospheric sulfate aerosols and the evolution of their vertical profiles. MODIS and MISR can provide a high resolution view of the spatial distribution of stratospheric aerosols and data from SAGE III, MODIS and MISR can be used to monitor the evolution of the size of these aerosols.

Total Solar Irradiance. ACRIM will provide systematic monitoring of total solar irradiance variations, which are essential to separate anthropogenic forcing from natural variations.

2. What is the ability to predict climatic anomalies a season in advance and what is the mechanism for verifying, distributing, and using these results? One to two years in advance?

Seasonal Prediction. Seasonal prediction is based on accurate knowledge of the initial state of the slowly varying components of the climate system, particularly the ocean and characteristics of the land surface such as soil moisture, snow cover and vegetation. The accuracy of these forecasts will likely depend on the accuracy with which we can measure the global state of the earth system. The entire suite of EOS observations which define the characteristics of the upper ocean and land surface will provide important boundary conditions for predictions. EOS scatterometer and altimeter measurements, coupled with in situ measurements, will provide the key data for initializing the state of the upper ocean for seasonal climate forecasts. Global-scale, near-real-time documentation of anomalies in regional precipitation, evaporation, snow cover, sea ice and cloud cover will allow the state of the land component of seasonal forecast models to be initialized and verified. MODIS, through its capability to monitor the extent and vigor of vegetation, will provide drought monitoring in semiarid environments.

In addition, EOS will provide data to test how these boundary conditions interact with the atmosphere and the entire climate system, thus leading to improvements in the prediction models themselves. EOS will provide critical process information on air-sea interaction and cloud-climate interactions which are major limitations in current climate forecasts and coupled atmosphere-ocean-land-ice climate models. EOS observations from the full suite of surface and sounding sensors (particularly for temperature, humidity, clouds and radiation) and 4-D assimilation efforts will contribute to forecast validation.



A comparison, by Greg Jenkins and Eric Barron (Barron IDS Investigation), of observed precipitation over the U.S. for spring 1980 with predicted precipitation from a General Circulation Model (GENESIS) which has spring 1980 sea surface temperatures specified. The bottom panel illustrates the improvement in prediction when the NCAR / Penn State mesoscale model is imbedded in the coarser resolution global model illustrated in the middle panel.

3 LONG-TERM CLIMATE CHANGE INCLUDING GLOBAL WARMING

The National Interest

Human activities are leading to changes in the land surface and the composition of the atmosphere with significant potential to cause decadal climate change with potentially significant impacts on energy utilization, agriculture, natural ecosystems, water availability, water quality, and sea level.

Scientific Background

The alteration of the land surface modifies the energy-water-vegetation interaction at the land-atmosphere interface. Physically-based models indicate that changes in the surface energy and moisture budgets can have a significant impact on regional climates. Increases in carbon dioxide and other greenhouse gases influence the global energy budget, promoting global warming and related climate changes. The detection of global warming is the subject of considerable debate, as the observing system in place over the last 100 years is inadequate to isolate long-term natural variability from human-induced change, and lacks the capability to determine small changes in global temperature. Consequently, an assessment of global warming is dependent on the predictions of climate models. State-of-the-art general circulation models predict a global warming of between 1.5 and 4.5 °C and substantial changes in precipitation and evaporation for a doubling of the atmospheric carbon dioxide concentration. Improved estimates of mean sea level change, on both local and global scales, as a means of detecting the consequences of greenhouse gas induced global warming, is an important adjunct requirement. A climate change of this magnitude will have significant impact on energy utilization, agriculture (drought and floods), natural ecosystems, water resource availability, water quality, and, potentially, sea level. However, the potential impact is very different for a 1.5 °C warming, as opposed to a 4.5 °C warming. The magnitude and rate of global climate change define the potential impact on society.

Science Requirements to Address National Needs

- Plausible scenarios for regional climate and ecosystem change, suitable for impact analysis.
- Improved estimates of the relative global warming potential for various gases and aerosols, including their interactions and indirect effects of other chemical species.
- Improved ability to determine the regional sources and sinks for atmospheric carbon dioxide, as part of the monitoring system for greenhouse gas emissions reduction agreement.
- Reduction in the range of predictions of the rate and magnitude of global warming over the next century (through reductions in the uncertainties of cloud-climate interactions and ocean heat storage).
- Predictions of anthropogenic interdecadal changes in regional climate, in the context of natural variability.
- Detection, beyond reasonable doubt, of greenhouse gas induced global warming, and documentation of other climatically significant changes in the global environment.
- Improved understanding of the interactions of human societies with the global environment, enabling quantitative analyses of existing and anticipated patterns of change.

EOS CONTRIBUTIONS

The detection of climate change, the reduction in the uncertainty associated with climate change, the improvement of estimates of global warming potential and sources and sinks of greenhouse gases, and improved prediction of regional change, including natural variability, depend on (1) an adequate monitoring capability, (2) improved knowledge of the forcing factors, (3) improved predictive capability to determine the response of the climate system, and (4) an assessment of the uncertainties. The Earth Observing System contributes to each of these fundamental components required to serve national needs. The synergy between many observations and many investigators will allow EOS to contribute understanding of the more complex, yet essential, earth processes, such as the hydrologic cycle. For long term climate change the key questions and EOS contributions are:

1. What are the human-induced and natural forcing changes in the global system and climate?

Knowledge of the nature of the climate forcing factors is essential to the prediction of future global change. The key forcing factors are modifications to the land surface, changes in radiatively important gases, aerosol loading in the atmosphere and solar variability. With the exception of atmospheric carbon dioxide concentrations we lack sufficient information to characterize a or to isolate the important human-induced and natural forcing factors. EOS provides essential information for each major forcing.

Land Cover Change. MODIS, ASTER and MISR will characterize changes in land surface cover and surface vegetation, with the capability to provide long-term monitoring capability. EOS will provide surface fluxes of energy and carbon with unprecedented accuracy and spatial resolution. In conjunction with historical observations, the human alteration of the landscape can be mapped and utilized to determine the potential impact on climate.

Radiatively-Important Trace Gases. MOPITT and TES will measure CO and CH_4, and TES will measure H_2O, O_3 and N_2O, all of which are needed to begin to separate human and natural greenhouse forcing. EOS measures of ozone depletion (see section on ozone and UVB) will define the abundances and trends of this radiatively important gas. MODIS measures of biomass burning will contribute to knowledge of trace gas emissions.

Aerosols. MODIS, MISR and EOSP will detect regional and global changes in tropospheric aerosols. Sulfate aerosols will be mapped and monitored by SAGE III; total column abundance of aerosols will be measured with MISR; volcanic gases can be measured with TES and MLS. Consequently, EOS will assess the role of volcanism as a natural forcing factor in the global system. The role of volcanism versus human-induced aerosol loading can be deciphered based on the chemical imprint of volcanoes, monitoring volcanic eruptions and examination of trends in aerosol loading.

Solar Variability. ACRIM will measure solar total irradiance, a fundamental measure of solar variability, which is needed to separate human and natural greenhouse forcing. SOLSTICE will measure the total variation of UV, and its contribution to the natural variability of ozone.

2. What has been and will be the response of the climate system to human forcing?

An assessment of the response of the climate system to human forcing depends on our ability to determine the importance of the major forcing factors and to validate climate model response. The degree to which uncertainties in climate model predictions can be eliminated is also of considerable significance.

Climate Sensitivity. EOS investigators will complete extensive model experimentation aimed at quantitative comparison of the different human-induced and natural forcing changes. These sensitivity experiments will be completed at both regional and global scales. The response of the climate system will be defined by modeling efforts of the EOS investigators based on quantitative understanding of the natural and anthropogenic forcing from aerosols (MISR, SAGE III, EOSP, CERES, MODIS, HIRDLS), solar irradiance variations (ACRIM), land surface changes (MISR, MODIS, ASTER), and radiatively important gases measured by EOS (H_2O, CH_4, O_3, CH_4, N_2O, F_{11}, F_{12}) and from other sources (CO_2). EOS provides an unprecedented opportunity to assess the response of the climate system based on the full spectrum of forcing factors.

"Measurement of the major climate forcing factors by EOS is a prerequisite for detection of human-induced global change beyond reasonable doubt."

Climate Response and Validation of Predictions. The long term measure of water vapor, atmospheric temperature, cloud properties and sea surface temperature (AIRS / AMSU / MHS, MODIS, CERES) are essential to detection of global change. AIRS / AMSU / MHS will determine the three-dimensional structure of moisture in the troposphere and will measure the spectral changes in the longwave radiation going to space which are needed to monitor the effects of climate change, including the role of trace gases in global warming. HIRDLS will measure stratospheric cooling, a major expected signal of greenhouse warming. EOS ALT and other precursor altimeter missions will provide a well-calibrated long-term measurement of absolute sea level. The accurate monitoring and prediction of the mean sea level on a global basis provides a means of detecting the effects of greenhouse gas induced global warming. The identification of sea level rise would have a significant economic and societal impact. The characterization of clouds (CERES, MODIS, ASTER, MISR, AIRS), the radiation balance (CERES), temperature and humidity (MODIS, AIRS / AMSU / MHS), winds (scatterometer, EOS-ALT) and ice and snow cover (MIMR, MISR, MODIS) provide unique capability to validate model predictions.

3. How do human-induced changes compare to variations and changes in the natural system? Can these changes be detected and modeled?

Measurement of the major climate forcing factors by EOS is a prerequisite for detection of human-induced global change beyond reasonable doubt. In addition, EOS observations of the temporal and spatial variability of aerosols, vegetation, temperature, water vapor, ozone and clouds are essential to define natural variability.

Observations of Climate Variability. EOS will assess variability due to cloud interactions, vegetation changes, carbon / trace gas perturbations, and the major climate forcing factors. EOS 4-D assimilation models will provide a physically-consistent global measure of climate change.

Separating Natural Variability and Human-Induced Change. EOS investigators will apply these satellite observations to assess the possible cancellation of global warming due to increased greenhouse gas concentrations by aerosol loading of the atmosphere. The monitoring of aerosols, cloud properties, ozone and water vapor will provide a basis for improved estimates of the relative global warming potential of various gases and aerosols, including interactions and indirect effects. The location, duration, and type of activity associated with large volcanic eruptions, which is also a major source of uncertainty, will be monitored by EOS, allowing an isolation of human-induced and natural aerosol loading in the atmosphere. MISR bidirectional reflectance measurements will distinguish between natural or human-induced land surface cover and surface albedo variations, related to desertification, irrigation, deforestation and urbanization.

Modeling the Roles of Natural Variability and Human-Induced Change. Characterization of aerosol characteristics (abundance, particle sizes, albedo, optical thickness) with MISR, MODIS and EOSP, in conjunction with cloud measures, can be used to determine the indirect effect of aerosols as cloud condensation nuclei to define the climate impact of aerosols, including their interactions. Measures of CO, and CH_4 assist in the direct measurement of potential global warming. The carbon balance of terrestrial ecosystems from satellites, for different regions and resolutions, will yield scenarios for fluxes under different climate conditions or land management conditions. Terrestrial vegetation characteristics and ocean productivity measures will aid in the determination of regional sources and sinks for atmospheric CO_2, N_2O and CH_4.

4. What are the uncertainties and what is the potential for surprises, including sudden changes and changes in the frequency and intensity of extreme events?

The primary uncertainties in climate model predictions include cloud-climate feedbacks, land-atmosphere and ocean-atmosphere interactions, high latitude ice and snow response and the coarse spatial scale of current climate models. EOS will provide significant opportunities to document surface fluxes of energy and moisture over the land surface and the oceans, to document regional and global radiation budgets required to understand cloud-climate feedbacks, and to determine ocean heat transport. EOS will provide the first opportunity to examine ice sheet mass balance. These elements encompass the major limitation in current climate models, and thus EOS will contribute substantially to the improved prediction of regional and global climate change in the next generation of climate models. These model predictions can be verified by long term observations or can provide estimates of the statistical likelihood of change.

Cloud-Climate Interactions. Uncertainties in cloud-climate feedbacks are regarded as one of the most important limitations of current models. The unparalleled measurements of clouds, cloud-radiation and water vapor will allow EOS investigators to incorporate much improved parameterization in climate models.

Atmosphere-Surface Interactions. EOS observations of surface temperatures, atmospheric temperatures and moisture, surface characteristics and winds will provide major opportunities to address the uncertainties associated with the fluxes of moisture and energy at the land-atmosphere interface and ocean-atmosphere interface and their parameterization in climate models.

Ocean Heat Transport. Synergistic measurements of temperature and humidity with ocean altimetry and scatterometry will provide a unique opportunity to improve estimates of ocean heat transport, a major uncertainty in our knowledge of the climate system.

High Latitude Ice and Snow Response. Current observations are inadequate to determine if the major ice sheets are growing or declining. The GLAS instrument will be the first opportunity to address this major uncertainty.

Sea Level. EOS ALT and other precursor altimeter missions will provide a well-calibrated long-term measurement of sea level.

Extreme Events. Models developed by EOS investigators provide one of the few opportunities to address the potential of changes in the frequency and magnitude of extreme events, and will also contribute to understanding of the frequency and intensity of other phenomena such as El Niño. Historical and pre-historical examinations of specific regions by EOS investigators will provide information on the frequency of extreme events and potential thresholds.

Spatial Scales. EOS investigators will utilize improved measurements of surface fluxes and clouds and radiation to develop high resolution model predictions suitable for regional prediction of climate change.

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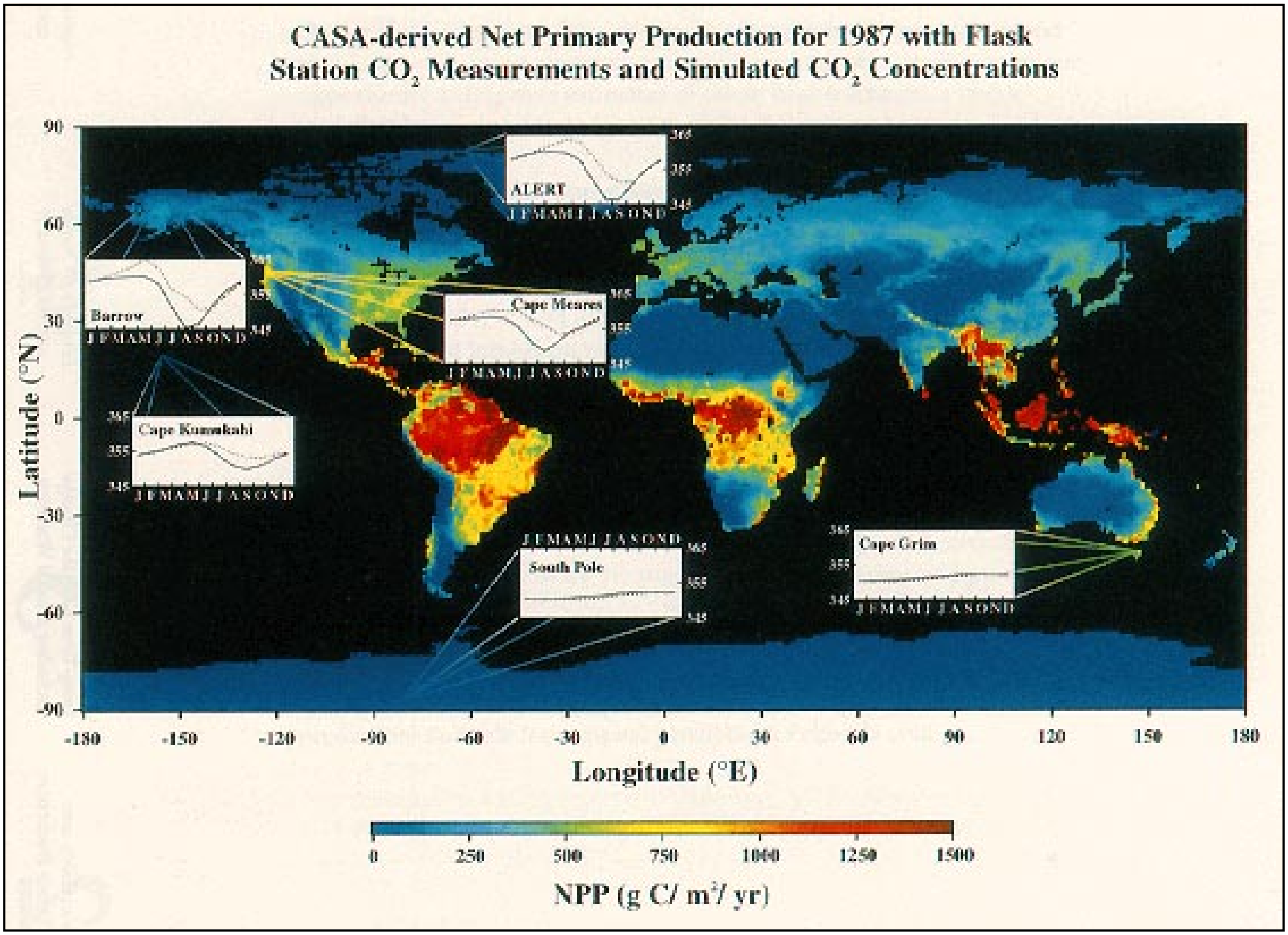


Global Terrestrial ecosystem models can be used to estimate key fluxes in the global carbon cycle. This figure shows a map of global, annual net primary production in the terrestrial biosphere, as predicted by the CASA model developed by the Sellers IDS team (Potter et al. 1993). The global integral from this model is 48 Pg C yr-1. In combination with estimates for ecosystem decomposition, ocean carbon exchange, fossil fuel emissions, and anthropogenic deforestation, this model yields a time-varying field of surface CO_2 exchange. Using a three-dimensional transport model to distribute the surface exchanges, atmospheric CO_2 concentration at several CO_2 monitoring stations were predicted (insets). The simulated dynamics of atmospheric CO_2 (dashed lines) were generally similar to the measurements (solid lines). Consistency with atmospheric measurements provides a strong test of any hypothesis concerning surface sources and sinks of carbon. The comparisons of simulated and observed CO_2 relied upon, in addition to CASA, the three-dimensional transport scheme developed by Scott Denning and David Randall, as part of Denning's research as a NASA Global Change Fellow.

4 ECOSYSTEM CHANGE AND BIODIVERSITY

The National Interest

Ecosystem function and biodiversity support human society in a myriad of ways and are under multiple stresses.

Scientific Background

Factors affecting the integrity of ecosystems, and their biological complexity and diversity, include changing patterns of land use and habitat fragmentation, effects of changing atmospheric composition, including effects of acidic deposition, ozone, and toxins, and possible changes in climate. The prevention of dramatic human-induced loss of species is a major responsibility, both from the view of species as natural resources and from our obligations for global stewardship. Changing patterns of land use directly affect the carbon storage of ecosystems and the global carbon budget, trace gas emissions, and biodiversity, by altering and fragmenting habitats. Traditional techniques for monitoring and managing ecosystems and biodiversity have been conducted at small scales, reflecting the techniques available and the scientific and management imperatives. As the effects of humanity, including possible effects on the global climate, become pervasive, ecosystem management increasingly requires analysis of large areas, taking into account remote influences via watersheds, mobility of organisms and the atmosphere.

Science Requirements to Address National Needs

- The detection of significant changes in ecosystems and biodiversity, determination of the response of ecosystems and biodiversity to the changes in atmospheric composition, UV-B, land use, climate and sea level, and the ability to attribute changes to specific mechanisms so that appropriate management interventions can be made.

EOS CONTRIBUTIONS

The Earth Observing System will map changes in patterns, and attributes of global ecosystems, and monitor rates of change over time. EOS measurements, in combination with models and ground observations will allow global inventories of land cover change, vegetation types, photosynthetic activity, and the extent and patterns of habitat fragmentation. EOS investigators will produce improved models of ecosystem response to anthropogenic and climate effects, extrapolated globally and calibrated with EOS data, for use in forecasting changes. Improved observations of climate, the oceans and volcanic events will provide better understanding of natural disturbances to ecosystems. EOS contributes substantially to several key questions:

"As the effects of humanity, including possible effects on the global climate, become pervasive, ecosystem management increasingly requires analysis of large areas, taking into account remote influences via watersheds, mobility of organisms and the atmosphere."

1. How do terrestrial ecosystems respond to changing climate, patterns of land cover change, and other disturbances?

Simultaneous Observations of Terrestrial Ecosystem, Land Cover and Climate Change. LANDSAT and ASTER provide primary observations of land cover, at the spatial scale of natural forest gaps, land clearing and other processes. Global observations using MODIS provide continuous measurements of global vegetation activity as it changes with the seasons, periodic disturbances such as droughts, and long term directional change. MISR provides the information required to correct LANDSAT, ASTER and MODIS for certain effects of the atmosphere, and land surface reflectance, critically increasing the reliability of the interpretation of land surface changes.

Biological Productivity and the Carbon Cycle. Models developed and utilized by EOS investigators will use information from the above sensors as inputs into calculations of the productivity and carbon storage changes of ecosystems, allowing inventorying of changes in biological productivity and the role of terrestrial ecosystems in the global carbon cycle. The same models can be used, once calibrated, to provide forecasts of the effects of climate change, land use change and disturbance scenarios. The results of these models will increase our basic understanding of ecosystems and provide input into decision- making related to forestry, agriculture, livestock production and watershed management.

Determination of the Patterns of Terrestrial Ecosystems and Ecosystem Change. Increasingly, biodiversity and ecological complexity are known to depend upon the size and spatial pattern of ecosystems. Many species require minimum area to successfully reproduce and survive; extinction probabilities are known to increase as habitats are reduced in size. In some cases, networks of smaller habitats can be successful if adequately connected by undisturbed corridors such as riparian zones, border vegetation or intentionally managed strips. Other organisms require large areas of habitat, with significant 'interior' areas away from the disturbances at forest, meadow and wetland borders. Remote observations with ASTER and LANDSAT provide direct information on such spatial patterns, and how they change over time.

EOS investigators will measure changes in land cover patterns in critical areas of the world, and will work with ecologists, systematists and conservation biologists to link space-based information on spatial pattern to ground-based data on diversity. This information will contribute to the large scale understanding of biodiversity and will provide information for use in local, regional and transnational decision-making regarding biodiversity.

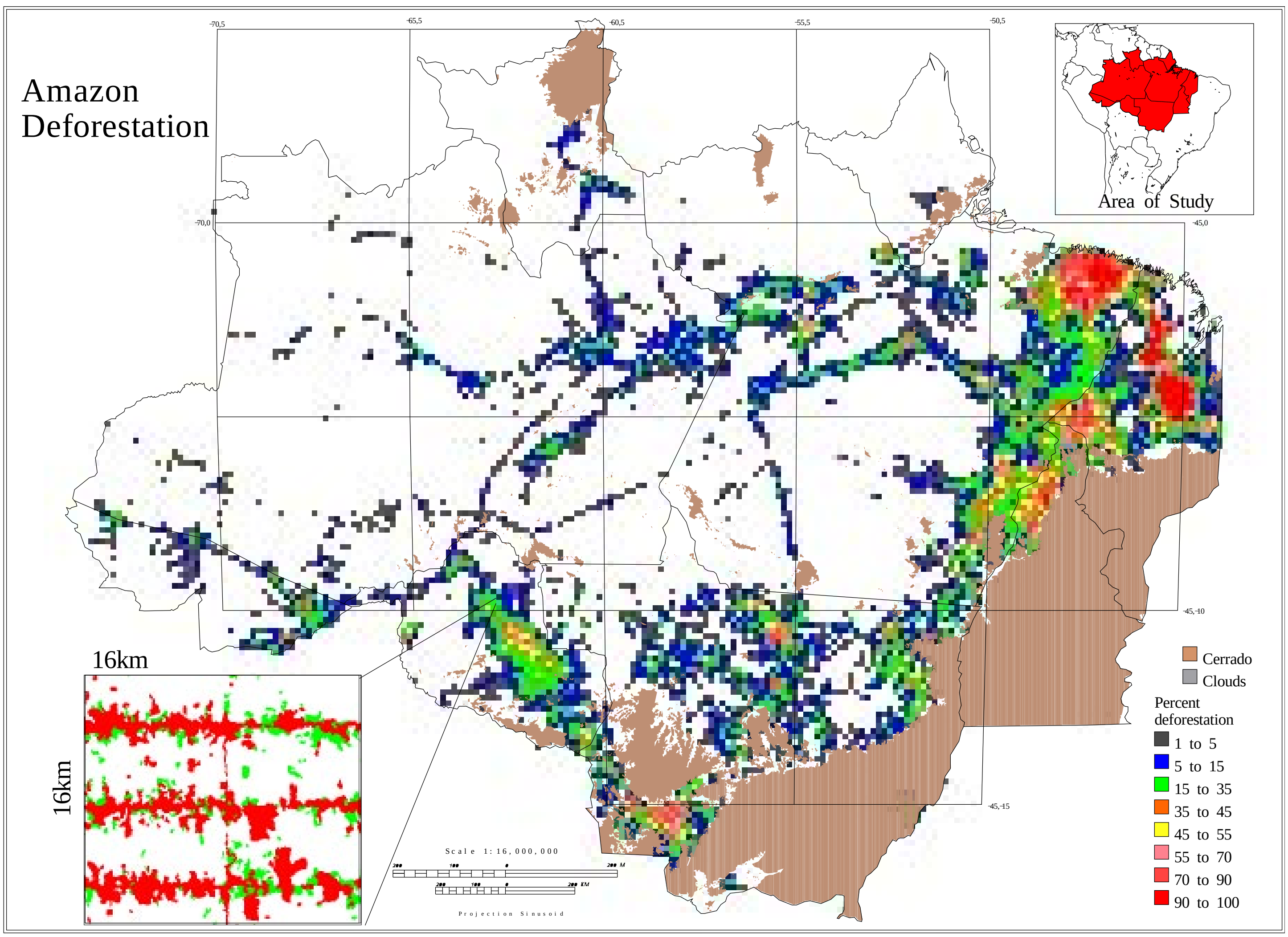
2. What will be the impacts of global change on marine ecosystems?

Ocean Biotic Responses. Observations of the marine biota, using ocean color from MODIS and SeaWifs, and observations of ocean physical processes (winds and currents) will provide information on the response of the biota to changes in physical factors such as solar radiation, winds and air-sea exchange. Global ocean color observations will provide a global view of marine productivity, and will complement the necessarily sparse network of direct observations. Detailed observations in coastal zones will allow linking of marine biological responses to physical factors, river inputs and pollution. In conjunction with global observations and modeling of ocean circulation, EOS ocean color observations will aid in modeling the role of the oceans in the global carbon cycle.

Information on marine ecosystems will be useful to decision-makers concerned with the carbon cycle, coastal zones, fisheries, pollution and navigation.

3. What are the possibilities for surprises and nonlinear thresholds in global ecosystems?

Ecosystem Models. The direct global observation of ecosystems, and the climate and land use change factors which influence them, will provide a larger data base of ecosystem response than has ever before been available. Most ground-based studies do not provide a view of ecosystem changes over time, and at large spatial scales. EOS observations will provide a large data base of examples that may provide scenarios of abrupt changes, which could become widespread if directional climate change occurs. EOS models will likewise explore a wide range of possible global change scenarios. The EOS ecological models include an increasing number of nonlinear and threshold responses based on process studies and extrapolation using remote observations and will provide potential scenarios of abrupt change. The synergism of modeling and observation of ecological changes will add credibility to forecasts of potential abrupt changes.



Amazonian deforestation, as detected by remote sensing. This comprehensive analysis of deforestation in the Brazilian Amazon was developed from LANDSAT Thematic Mapper data by David Skole and coworkers at the University of New Hampshire as part of Berrien Moore III's IDS Investigation. This type of information is crucial for both analyses of the global carbon cycle, and humanity's impacts, and for improved land use planning and conservation at large scales.

5 HUMAN DIMENSIONS AND ECONOMICS

The National Interest

The potential magnitude of global change introduces the need to describe scenarios for global change including their limitations in order that national leaders can define strategies for mitigation or adaptation.

Scientific Background

The strategies for mitigation and adaptation may have widely different economic and societal impact, involving health, standard of living and quality of life. Knowledge of the rate and magnitude of global change and its impact at global and regional scales is essential to assess social and economic impact. Even moderate climate change may result in significant changes in the distribution and availability of critical resources such as water. We must be able to understand the nature of the human forcing of global change, particularly land and energy use. Without these scientific foundations, the strategies for mitigation or adaptation may be misguided, resulting in either inadequate or unnecessary policies.

Science Requirements to Address National Needs

Definition of the interactions of global change with the major areas of societal activity, useful for the development of rational adaptation and mitigation strategies.

EOS CONTRIBUTIONS

The Earth Observing System addresses natural hazards, such as volcanism, but most importantly provides a realistic basis for understanding the potential rate and magnitude of global change. Therefore, EOS studies will define the vulnerabilities of water resources, agriculture and ecosystems to climate change. EOS will provide fundamental data sets on land cover change, clearly addressing the need to understand one of the most significant human forcing factors of global change. EOS will also provide fundamental measures of sea level change, a major factor in coastal regions. The key questions and EOS contributions are:

1. What are the interactions with agriculture?

Land Cover Changes. MISR, ASTER and MODIS will assess changes in land cover, surface albedo, biomass burning, and productivity as a basis to assess human activity and to define the interactions between climate, land use and agriculture.

"Knowledge of the rate and magnitude of global change and its impact at global and regional scales is essential to assess social and economic impact. Even moderate climate change may result in significant changes in the distribution and availability of critical resources such as water."

Enhanced Climate Prediction. EOS observations (AIRS / AMSU / MHS) and regional and global climate change predictions from EOS investigators can be the basis for determining potential changes in agricultural yields, agricultural management and implications for land use.

Radiatively Important Gases. EOS focus on radiatively important gases from agriculture, and ozone plus ozone depletion catalysts may influence management practices.

2. What are the interactions with freshwater resources?

Enhanced Climate Prediction. EOS climate predictions at global and regional scales will emphasize the water balance and its sensitivity to global change, providing a major requirement to assess water resource vulnerability to global change.

Monitoring of Resources. EOS monitors of snowcover and glaciers at a regional and hemispheric level (MODIS, MIMR) provides a basis for short term assessment of a significant water resource component. GLAS and EOS-ALT will measure global ice sheet mass balance.

3. What are the interactions in the coastal zone and marginal sea ice zone, including fisheries?

Marine Productivity. High resolution coastal circulation studies, including biology, will provide important data on primary productivity, a key element in fisheries.

4. What are the interactions with human health, including disease vectors, air quality, and UV-B radiation?

Ozone Depletion. MLS, HIRDLS and SAGE III provide diagnostic information on ozone depletion by monitoring enhancements in precursor chemical radicals. This gives the capability for providing early warning potentials for increased UV-B.

Air Quality. TES and MOPITT will provide a large number of measurements (O_3, CO, CH_4, NO, NO_2 and HNO_3) which will greatly aid our understanding of the chemistry of the troposphere.

Volcanic Hazards. TES, MISR, ASTER and MODIS will monitor volcanic gas hazards in association with major eruptions which have the potential of human impact.

5. What are the interactions with land use, including soils and erosion?

Land Cover Change. EOS instruments will provide unprecedented measurement of the scale and magnitude of changes in land cover associated with land use change.

GLOSSARY OF ACRONYMS

ACRIM	Active Cavity Radiometer Irradiance Monitor
AIRS	Atmospheric Infrared Sounder
ALT	Altimeter
AMI	Advanced Microwave Instrument
AMSU	Advanced Microwave Sounding Unit
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High-Resolution Radiometer
CERES	Clouds and Earth's Radiant Energy System
CFC's	Chlorofluorocarbons
CHEM	Chemistry Platform or Instruments
CLAES	Cryogenic Limb Array Etalon Spectrometer
COLOR	Ocean Productivity
EOSP	Earth Observing Scanning Polarimeter
ERS	European Remote-Sensing Satellite
ENVISAT	Environmental Satellite (European Space Agency)
HALOE	Halogen Experiment
HIRDLS	High-Resolution Dynamics Limb Sounder
IDS	EOS Interdisciplinary Science Investigation
IR	Infrared
ISAMS	Improved Stratospheric and Mesospheric Sounder
MHS	Microwave Humidity Sounder
MISR	Multi-Angle Imaging SpectroRadiometer
MLS	Microwave Limb Sounder
MODIS	Moderate-Resolution Imaging Spectroradiometer
MOPITT	Measurements of Pollution in the Troposphere
NSCAT NASA	Scatterometer
SAGE	Stratospheric Aerosol and Gas Experiment
SBUV	Solar Backscatter Ultraviolet
SOLSTICE	Solar Stellar Irradiance Comparison Experiment
TES	Tropospheric Emission Spectrometer
TOMS	Total Ozone Mapping Spectrometer
TOPEX / Poseiden	Ocean Topography Experiment
UARS	Upper Atmosphere Research Satellite
UV-B	Ultraviolet-B